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Measuring the α/SF Branching Ratio of ^{252}Cf with the NIFFTE TPC

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A fission TPC is being developed to measure the energy-dependent neutron induced fission cross sections of the major and minor actinides to an accuracy of better than 1%. Achieving such an accuracy will depend in part, on the ability of the TPC to provide precise tracking and identification of charged particles. A measurement of the α-decay to spontaneous fission branching ratio of ^{252}Cf used to benchmark the performance of the TPC will be discussed.

I. INTRODUCTION

The Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) collaboration is developing a fission Time Projection Chamber (TPC) to measure energy-dependent neutron-induced fission cross sections to an accuracy of better than 1%. To achieve a high level of accuracy in fission cross section measurements the systematic uncertainties associated with previous detector systems, such as fission chambers, must be addressed. The fission TPC allows for detailed event reconstruction and charged particle tracking, and will provide the ability to investigate many of the systematic errors of previous fission cross section measurements.

Typically, neutron-induced fission cross sections are measured by placing a thin target of the fissionable material (usually on a backing) of interest into a neutron beam and detecting the ionization left in a gas by the resulting fission products. This is usually accomplished with the use of a fission chamber. Fission chambers can also detect the α-decay of the fissionable target material, and many of the other neutron-induced reactions resulting in light charged particles. Because fission chambers only measure the energy deposited in a gas by charged particles, they are incapable of distinguishing between different particles with the same energy. Fission fragments generally have a much higher energy then α-particles, but because the fragments are subject to energy loss and straggling within the target and backing material, it is possible that they can lose enough energy so as to become indistinguishable from the lighter charged particles within the fission chamber, resulting in a systematic error in the measured cross section.

The fission TPC differs from a fission chamber, mainly in that it provides 3-dimensional images of charge particle tracks in the detector. This provides for, not only a measurement of the particle energy but also a reconstruction of its track length and specific ionization. Thus particles of differing mass and charge, but with equal energies can be distinguished from one another. ^{252}Cf which undergoes both α-decay and spontaneous fission (the branching ratio of which has been well measured in the past [1, 2]), provides a good test case for fission TPC development.

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II. THE FISSION TPC

The fission TPC consists of two hexagonal, highly segmented anodes, or pad-planes, placed on either end of a cylindrical field cage with a central cathode. Each segment of the anodes is read out individually. In this way 2-dimensional information of a particle track can be determined. By measuring the relative time of the signals on each segment, the third dimension of the track's orientation can be projected. The specific ionization of a charged particle track in a gas is dependent on the ion's mass, charge and energy. One consequence of this is that charged particles of equal energy but different mass and charge will have different track lengths. Fig. 1 shows the track length vs. energy deposition of α-particles and fission fragments from ^{252}Cf as measured by the fission TPC. In the lower energy region, events that may have been difficult to distinguish based solely on energy are now clearly separated. The shape of the specific ionization curve can be also be observed with the TPC, providing an even more powerful tool for particle identification. For this measurement however, only the track length and energy information were utilized for identification.

At the time of this measurement, the fission TPC had one sextant of one hexagonal pad-plane instrumented, 1/12 of its total possible 4π sr coverage. A 100 nCi ^{252}Cf source was mounted on the cathode such that it was fully within the active area of the detector. The source had

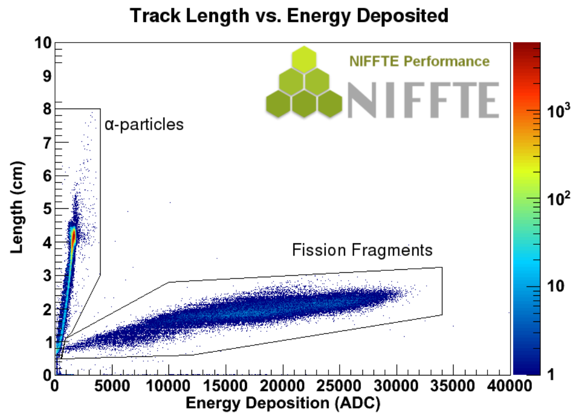

FIG. 1. The track length vs. energy deposited of charged particles emitted from a ^{252}Cf source as measured by the fission TPC. The lower energy band on the left of the plot is α-particles and the high energy, short tracks are fission fragments.

a thin, 100 μg/cm^2 gold covering and a thick platinum backing therefore the available solid angle for the emission of charged particles was 2π sr. The distribution of the cosine of the polar angle is expected to be flat for an ideal source. For a 2π, single-sided, thick backing source, scattering in the backing, covering, and source material alters both the angular distribution and emission rate.

Backscattering occurs when a charged particle, incident upon the surface of a material, undergoes multiple small-angle scatters in that material, the cumulative effect of which alters the particle trajectory away from the surface. The effect is largest when the initial trajectory of the charged particle is at a grazing angle with the surface of the material. The backscattering of α-particles and fission fragments is a well known effect [3–6], and when working with a single sided source it can generally be minimized by collimation because of its angular dependence. Collimation was not necessary nor desired for this measurement however, because the TPC can observe the effect directly. Moreover, one of the particular systematic uncertainties of fission chambers that the TPC will be used to investigate is straggling in the target, which is directly related to backscattering.

Fig. 2 shows the polar angle distribution of ^{252}Cf α-particles as measured in the fission TPC compared to a simulation. The simulation was performed with SRIM [7] and includes the effects of the platinum backing and gold covering of the previously described source used for the measurement. The simulation does not include any of the detector effects. The simulation and data are in good agreement regarding the peak near cosine polar angle of 0 resulting from scattering in the platinum backing. The data shows another peak not seen in the simulation at cosine polar angle of -1. This is a detector effect whereby low energy, scattered α-particles deposited energy over only a few segments of the anode and the tracking algorithm was unable to make an accurate determination of the polar angle.

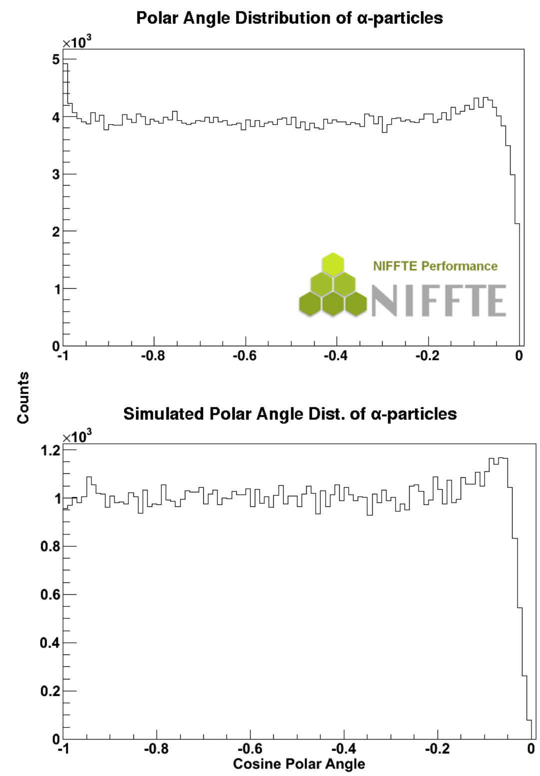

FIG. 2. A measurement of α-particle track polar angles from a ^{252}Cf source (top) and a SRIM simulation of the source (bottom) which includes the effects of scattering in the platinum backing and gold covering. A cosine polar angle of 0 is defined as being parallel to the source surface.

Based on the literature [8, 9] and simulations and analysis conducted by this author, it was determined that for the purposes of this measurement SRIM could be relied upon to calculate a backscattering correction for the ^{252}Cf α-particles. The ability of SRIM to accurately calculate the backscattering of fission fragments however is less certain [10, 11]. In principle, for a 2π detector the backscattering correction needed for fission fragments is much less than that needed for α-particles as a fission decay always results in at least two fragments that are emitted nearly back-to-back. Thus when a fission fragment backscatters into the active area of the detector it will be accompanied by its complementary fragment and be detected as a somewhat higher energy fission event that would have been detected even had backscattering not occurred. The situation for this measurement was somewhat complicated by the fact that the detector coverage was less than 2π. The limited angular coverage meant that a fission fragment which backscattered into the active area of the detector, when its complementary fragment was not emitted into the active area, should not count towards the ratio being measured. To address this the source was placed such that it was fully within view of the active area of the detector and events where a fission fragment backscattered could be identified as such. The placement of the source was not ideal however and some fission backscattering events were likely misidentified resulting in a potential source of systematic error. Another source of error results from the use of simulations to estimate the number of fission fragments that were stopped in the source covering. A detailed description of the measurement and analysis are reported in [12].

III. CONCLUSIONS

The goal of this measurement was to develop the particle tracking and identification abilities of the fission TPC and benchmark its performance against the previously measured value of the α/SF branching ratio of ^{252}Cf. The main sources of uncertainty in this measurement generally resulted from the fact that the TPC was only partially instrumented and the use of a source with a thick platinum backing and gold covering which exaggerated the effects of scattering. A direct observation of the scattering in the source was nevertheless a valuable exercise in the development of the fission TPC. The preliminary analysis this measurement suggest that the fission TPC is capable of addressing the systematic uncertainties of neutron-induced fission cross section measurements caused by scattering in the target. Work is currently proceeding on a measurement with the fully instrumented fission TPC using an uncovered thin-backing ^{252}Cf source, an analysis of which will be reported in a pending publication.

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